ESTIMATION of SEQUESTERED CARBON in KING COUNTY FORESTS

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Project Report

to

King County DNR

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SUMMARY

The purpose of this project was to produce both a current and near-term future inventory of carbon sequestered in trees on forested landscapes in King County, Washington, U.S.A. Recognizing that there may be differences between predominant management activities on lands with different owners, and to make the study compatible with other reports generated at the state and county level, the inventory was stratified by ownership. Recognized ownership categories are the following: Forest Industry (FI), Miscellaneous Private (MP), State (DNR), Forest Service (FS), and County / Municipal / Misc. Federal (CMF). The process used to assess sequestered carbon required three steps.

The first step was to acquire the inventory data sets to be used and to pre-process them into a format that could be used with existing and emerging analysis tools. Second, a realistic categorization of forestland in King County into the recognized ownership classes was made. In the third step, the inventory data was synchronized to the year 2000, which involved simulating growth of the forest and its dynamics on older inventory records to update them to the present, then converting the common year updated inventory into carbon equivalents.

Given that the bulk of the data for this study came from the Pacific Resource Inventory, Monitoring, and Evaluation (PRIME) program on the West Coast as administered through the federal Forest Inventory and Analysis program, that ownership classification was deemed most suitable for the purposes of this study.

Table 4. Area of all forestland by ownership class in King County as imputed from Tables 7, 9W and 10 from Bolsinger et al. (1997).

Ownership Class	Area (acres)
Forest Industry	279,659
Misc. Private	144,808
State (DNR)	90,553
Forest Service	166,437
County / Municipal / misc. federal	139,543
Total	821,000

Attempts were made to refine these estimates using the King County GIS database, which includes taxpayer names, zoning information and a canopy layer. The total acreage above agrees to within 1.4% of the total acreage derived from the King County database. In reality, it does not matter if any of these individual ownership classes is smaller or larger than estimated, because carbon content is determined solely by the forest types, ages and stand structures, not by who owns the parcel. The classes however, do serve in application of harvest removals that are estimated from annual DNR harvest reports. These acreage figures include reserved timberland, other reserved forestland, and unreserved other forestland as classified in the Bolsinger, et al. (1997) report.

The Westside Cascade variant of the Forest Vegetation Simulator (FVS) was used to synchronize, or update, individual tree inventory records to a common base year, incorporating all reported harvest activity. The resulting individual tree dimensions were used to estimate first biomass of individual tree components (stem, bark, branches and coarse roots), which then were converted into carbon equivalents. These activities were coordinated through the Landscape Management System (LMS), developed in the

Silviculture Lab at the College of Forest Resources, University of Washington. The calculations involved indicate that he carbon pool represented by trees in forestland in King County appears to be evolving in the following fashion.

Table 6. The estimated carbon pool (metric tons) in live trees (stems, bark, live branches, coarse roots, and foliage less litterfall) on forestland in King County, projected over time.

Ownership Class / Product Class		Actual, Updated, or Forecasted Inventory year			
		1995	2000	2005[a]	2005[b]
		(metric tons)	*(metric tons)*	*(metric tons)*	*(metric tons)*
Forest Industry	/ old growth	449,111	470,545	491,572	491,572
	/ young growth	13,224,685	12,939,566	12,374,537	12,071,555
Misc. Private	/ old growth				
	/ young growth	9,457,434	9,675,425	9,721,302	9,721,804
State	/ old growth	1,448,980	1,492,952	1,534,815	1,534,478
	/ young growth	6,845,915	6,823,484	6,730,204	6,780,460
Other public	/ old growth				
	/ young growth	8,109,510	9,139,160	10,158,927	10,103,859
Forest Service	/ old growth[c]	7,412,618	7,967,593	8,139,367	8,139,367
	/ young growth	6,383,890	6,421,865	6,907,830	6,907,830
All owners	/ old growth	9,310,710	9,931,091	10,165,754	10,165,754
	/ young growth	44,021,434	45,009,499	45,892,799	45,585,508
All owners / All Product Classes		53,332,144	54,940,590	56,058,554	55,751,262

[a] Forecast based on rate of harvest similar to past five years, all harvests applied to young growth class.
[b] Forecast based on rate of harvest similar to past ten years scaled to a five year period, all harvests applied to young growth class.
[c] Changes in Forest Service old growth carbon values may include increases in acreage due to older young growth stands crossing the 100-yr threshold as well as growth on residual growing stock.

These carbon figures (in terms of tons per acre) are well within the range of those reported elsewhere (Harmon 2001, McArdle et al. 1949, Cooper 1983). Regardless of the direction or magnitude of any suspected bias in our carbon estimation method at a single point in time, the same biases (if any) are operating at each point in time so differences calculated between carbon values at different points in time will have canceling errors. Thus, it is quite likely that trends will be representative of what is happening in reality because of these canceling errors (cf. Wykoff, et al. 1982).

The estimates that appear here apply to the carbon pool in standing trees only. Harvest removals were considered only to deplete the carbon pool in the forest in this study. What happens to the sequestered carbon after it leaves the forest also should be considered. That is to say, larger questions regarding long-term carbon sequestration would include those that revolve around life cycle analysis and what is found in wood product pools (see, for example Bowyer, et al. 2002). For example, much sequestered carbon is potentially stored for quite a long time in a house built of framed wood 2x4 construction. Answers to questions like this will help reveal all the missing pools and fluxes affecting both *in situ* and *ex situ* sources of sequestered carbon.

INTRODUCTION

The concentration of atmospheric carbon dioxide (CO_2) is increasing, with much of the increase often being attributed to emissions from anthropogenic sources (Johnsen et al. 2001). Because CO_2 is considered one of the "greenhouse" gases, which trap exiting solar radiation, there are concerns that this increasing concentration may result in climate change. Recent increased international pressure to reduce net carbon emissions in the United States and around the world has motivated the question of whether or not forests can sequester a significant amount of these emissions, thus offsetting human-originated emissions. In one large-scale assessment (Birdsey and Heath 1997), US forests are reported to have sequestered enough carbon to offset approximately 25 percent of US emissions over the past 40 years. Undoubtedly, Pacific Northwest forests have played a large role in this sequestration. While such large-scale assessments have utility for national or other broadly based objectives, more detailed, or local assessments will provide the resolution required for other purposes, for example, in issues surrounding the use of carbon credits. King county contains approximately 7% of all forestland in Western Washington (by area), according to Bolsinger et al. (1997). Therefore, treatment of forests in King County will have a detectable impact on the carbon pool in western Washington and the state as a whole. Motivation for this study came from King County Administrators, through the operation of the Greenhouse Gas Assessment Committee. Interest was generated in making an assessment of the carbon pool in forested lands in King County, Washington, both now and into the near future.

The first step in producing an estimate of sequestered carbon will be to evaluate the magnitude of influences on the major *in situ* carbon pools. There are two major *in situ* carbon pools, above- and below-ground biomass. The estimates produced in this study of sequestered carbon represent what is captured in trees only and includes bolewood, branches, and roots. Standing dead snags, large woody debris, logging "slash" and other sources such as the soil are not considered. This is not to say that the carbon in the soil is not important, in fact the largest pool of organic carbon in most forest stands is soil organic matter and detritus (Schlesinger 1977). Major studies have, however, shown that harvesting will not cause soil carbon losses (Boone et al. 1988, Harmon et al. 1990). Thus, an assumption of relatively constant soil organic carbon is tenable over a wide range of management scenarios, but radical changes in management objectives such as changing land use must be excluded from this generalization.

Land use does, in fact, appear to be the major influence on the potential size of a carbon pool, while management regimes heavily influence the capacity to reach that potential (Harmon 2001). Forecasting land use changes, i.e., from forest to non-forest, for example, were beyond the scope of this study, however.

The objective of this project was to produce both a current inventory (estimate) and near-term future inventory of carbon in trees on forested landscapes in King County, Washington, U.S.A. Recognizing that there may be differences between predominant management activities on lands with different owners, and to make the study compatible with other reports generated at the state and county level, the inventory was stratified by ownership. Ownership classes recognized for this study are Forest Industry (FI), Forest Service (FS – primarily Mt. Baker-Snoqualime National Forest), State owned lands (DNR), Miscellaneous Private (MP – all private non-industrial), and county/municipal/misc. other federal lands (CMO).

DATA AND METHODS

The chief data sources for this study were the Forest Inventory and Analysis permanent sample plots located in King County, WA (see Bolsinger, et al. 1997, for a summary of the entire state) and the Mount Baker-Snoqualmie National Forest Current Vegetation Survey. Each data source is described separately in the sequel.

The age of each of the data sets was different, approximately eleven years old for the FIA data and six years for the MBS data. This necessitated updating the inventory records to the present by using an appropriate forest growth simulation model. The simulation model used to accomplish this updating was the West Cascades (WC) variant of the Forest Vegetation Simulator (FVS). Donnelly and Johnson (1997) describe the WC variant of FVS in detail, and Wykoff (1997) provides theoretical background on the model framework. Harvest records, both volumes and acreage involved were provided by Washington Department of Natural Resources and were utilized to diminish simulated carbon yields appropriately over the span of years from 1990 to 2001.

Tree dimensions and volumes were converted into stored carbon using the methodology employed in a post simulation process developed to support an analysis of Life Cycle Inventories by the Consortium for Research on Renewable Industrial Materials (CORRIM) after growth simulation was completed (Manriquez 2001). This methodology essentially uses species-specific equations from the literature to compute estimates of biomass components (boles, branches, roots, etc.) from easily measured individual tree characteristics such as DBH (Diameter at Breast Height) and total height. Information on tree component biomass conversion to stored carbon was similarly taken from the literature and developed also through consultation with the CORRIM Forest Resources Technical Advisory Committee (Johnson 2000). Further details are provided in the sequel.

The Landscape Management System (McCarter et al. 1998) integrates all these tools into a single framework to perform simulations and provide a broad spatial and temporal context for carbon storage evaluation at the tree, stand, landscape and county level. The Landscape Management System (LMS) is an evolving software application developed at the University of Washington College of Forest Resources Silviculture Laboratory. LMS is designed to assist in landscape level analysis and planning of forest management alternatives. LMS is implemented as a Microsoft Windows (TM) application that coordinates the activities of other programs (projection models, visualization tools, etc.) that makeup the overall system. Since LMS is a modular system it can accept many growth model alternatives for use with simulations.

The same methodology was used to project the carbon inventory beyond the present to the near-term only. Although long-term projections can produce quite precise estimates of differences between alternative treatment regimes (Wykoff et al. 1982), long term projections of a single treatment regime to estimate standing inventory at a single point in time may be subject to accuracy limitations. Therefore, future yields were forecasted to 2005 in two ways, once assuming that future five-year harvests would be similar to the last five years and second, assuming that future five-year harvests would be similar to the average periodic five-year harvests over the last ten years for comparison.

Forest Inventory and Analysis (PRIME) Data

The U.S. Forest Service is responsible for determining the extent, condition, volume, growth, and depletion of the Nation's forests on a periodic basis. This mandate was originally established by the McSweeny-McNary Forest Research Act of 1928 to determine the amount of timber available for harvesting. More recently, the Forest and Rangeland Renewable Resources Planning act of 1974 and the Forest and Rangeland Renewable Resources Research Act of 1978 extended the mandate to go well beyond an inventory of timber availability.

The Forest Service implemented the Forest Inventory and Analysis (FIA) program through its regional research stations to meet this objective. This effort is organized as the Pacific Resource Inventory, Monitoring, and Evaluation (PRIME) program on the West Coast. PRIME collects data on all ownerships except National Forests, reserved areas and census water. In Western Washington, this data is compiled in the Westside Data Base (WWDB) format, referring to the western United States (not just west of the Cascades Crest). The National Forest System is responsible for obtaining data on the land it administers.

The western Washington inventory design is a fairly standard application of double sampling for stratification (Cochran 1977) with both the primary and secondary samples on permanent grids. Aerial photo interpreted plots serve as the primary sample units and they are laid out on a 1.5km grid that was established on base maps or orthophotos in 1978 and transferred to aerial photos. Land areas are initially stratified into land use classes and were identified as to ownership, land class, degree of urbanization, and for forested plots, stage of development, major forest type, and stocking class.

Field plots serve as the secondary sample units and are laid out on a grid spaced at 6km intervals, providing one field plot per every 16 photo points. During 1963 –1966, a grid of 10-point field plots were established on all field grid locations in western Washington except in National Forests. In 1978 and 1979, new 5-point plots were established at these same grid locations. At each of the five points, trees 17.5 –90cm are sampled with a metric 7-factor prism. Trees 12.5 –17.4cm are sampled with a 3.3m fixed-radius plot centered on the prism point. Trees less than 12.5cm are sampled with the first quadrant of the 3.3m fixed-radius plot. Trees over 90 cm are sampled on a concentric 17m fixed radius plot. Thus, this is a nested plot design and the five points represent an area covering approximately 5ac. Field plot locations are not contained in the database mainly due to the proprietary nature of the private land holdings. Nevertheless, since the plots are located on a fixed grid, each ownership is sampled with similar intensity. Therefore, the proportion of plots in the database for a given ownership is in direct proportion to the actual acreage of that class across the entire county. The distribution of age classes and stand types in the sample will also reflect the actual distribution in the ownership.

The FIA inventory for western Washington used in this study was conducted in 1988/89 and by special agreement with the Washington Department of Natural Resources, the sampling intensity was doubled to about one in every eight primary sampling units. The inventory was completed in 1990 (MacLean et al. 1992). Plot level attributes of interest for this study include land class, ownership, county, site index, slope, aspect, county level expansion factors, and others. The WWDB set was screened using a county code of 33 (King) and a ground class of 20 (forest) resulting in 156 plots with 4,182 tree records for this analysis. Tree level attributes used in this study include breast height age, species, DBH and measured heights when available. Total tree ages were computed using site appropriate, species specific number of years to reach breast height. Plot ages were calculated as a density weighted average of individual tree ages for the purposes of the forest stratification used in this study.

Mount Baker –Snoqualmie National Forest Data

As stated in the previous section, the FIA project does not include in its mandate the census of National Forest land in its sample base. This leaves each National Forest responsible for inventorying land under its own jurisdiction. The Mount Baker –Snoqualmie (MBS) Current Vegetation Survey (CVS) was designed to address the need for continually inventorying, that is, monitoring change in the forest. Data from the USDA Forest Service Region 6 Current Vegetation Survey databases are in the public domain and are available on-line for downloading along with associated documentation from the Region 6 CVS website (http://www.fs.fed.us/r6/survey/).

Two databases are available for the MBS National Forest: Occasion 1 and Occasion 2. Occasion 1 data comprises 110 plot clusters, was collected during the inventory year 1995, and covers the entire MBS. Occasion 2 data was collected in 1998 and represents a sub-sample of 20 of the original 110 plot clusters. The Occasion 1 database was selected for use in this carbon assessment study for King County because of its relative completeness of coverage.

Like the PRIME survey, the MBS CVS is made up of clusters of five plots. The MBS NF clusters are laid out on two grid sizes, one spaced at 3.4mi. intervals, the other spaced at 1.7mi. in order to sample certain areas of the national forest with different intensity. Each grid intersection is given a location code (605 for MBS), an eco-class, age, slope, aspect, elevation, and latitude. Each grid intersection is then used to establish the first point, which has a large circular, 2.47ac plot used to sample the area for trees ≥ 48" DBH. Concentrically located smaller plots are used to measure smaller trees and vegetation. A 0.1887ac plot is used to sample trees between 13 and 48 inches DBH, a 0.0417ac plot is set up to sample trees between 5 and 13 inches DBH, and a 0.01ac plot is used to sample all remaining trees ≤ 5 inches. The other four points are laid out completely inside the first large 2.47ac plot along radii perpendicular to each other so as to sample each quadrant of the large plot. Each of these four points consists of the same three smaller, concentric plots described above and are used to sample the same ranges (strata) of tree sizes. Information available at the individual plot level includes inventory year, stand number, tree number, species, DBH, height, and crown ratio.

Every plot in the MBS database was missing a site index value, but this was not a concern because the WC variant of FVS contains an eco-class / site index mapping function for every species, therefore site indexes were derived within the FVS model. Thirty of the 110 plots were missing ages. Missing ages were estimated from an AGE-QMD regression fit to the remaining 80 plots that had measured ages. The proportion of variation in AGE explained by the regression was low, however this estimated age was deemed suitable for use when compared with the alternative of dropping the plots from the analysis since FVS does not require age as an input variable. Further, harvest records for King County over the decade 1991 –2000 indicated that less than 3.5% of the total harvest came from Federal sources, so the impact of mis-classifying a stand as young growth or old growth will be small.

Forest Stratification

Initially we hoped that the data sets would be of sufficient resolution to enable a fairly fine stratification of stands into ownership, age, species type, and site index classes for the purposes of simulating forest growth and drain by identifying prevalent management scenarios followed by the various land owners. Further, it was hoped that beyond ownership divisions, comparisons between stored carbon among species groups and / or age classes might be tracked over time. To this end, we initially attempted to classify the stands into five ownership classes, state lands (DNR), Forest Industry lands (FI), Forest Service lands (FS), Miscellaneous Private lands (MP), and County / Municipal / misc. Federal (CMF). State lands include all Washington State owned or administered land. Forest Industry land includes land owned by companies that grow timber for industrial use and includes companies both with and without wood processing plants. Forest Service lands include those lands that have been designated as National Forest and other lands under administration of the U.S. Dept. of Agriculture. Miscellaneous Private lands include all private lands not owned by Forest Industry and tribal and allotted lands held in trust by the Federal Government. Finally, County / Municipal / misc. federal lands include lands administered by all public agencies other than the Forest Service, U.S. Dept. of Agriculture including utility districts. Initially we used ten-year age classes (0-10, 11-20, 21-30, …, 121-130, 131+), so that we would be able to time silvicultural prescriptions more accurately using this resolution of age classes. Recognizing that management scenarios should vary according to species composition of the stand, we defined species composition classes by identifying the most predominant species present in a stand (≥ 70% of one species or species group), which led to six species classes (Douglas-fir, western hemlock, true fir, cedar, hardwood, and mixed). Initially, five site classes were chosen again, to be able to time the chosen silvicultural operations for each ownership more reasonably.

A number of obstacles made the simulation the harvesting that occurred over the past decade quite a challenge. First, it was recognized that a standard species would need to be chosen for site index determination upon which other species site indexes could be keyed. Douglas-fir was a natural choice, but site index of any kind was missing from the MBS data set. Unlocking the species / eco-class mapping used in the WC variant of FVS would not be difficult, but data formatting issues prevented a quick automation of the process, which meant species site index values would require manual input on well over 1,000 sub-plots.

Second, it became readily apparent that identifying a prevalent management scenario to simulate / approximate harvesting over the past decade for the purposes of updating the inventory was dubious at best for several of the ownership classes. This was particularly true for the MP and CMF lands, and even for the FS lands. Defining an "average" harvest schedule or pattern for MP landowners proved difficult, as well as for CMF landowners, not to mention the plethora of options and possible bifurcation points due to varying species compositions. Since these lands together made up nearly 30% of the land base, errors or biases introduced just at this level were potentially quite large.

Third, it would be necessary to check the accuracy of completely simulated harvests with published information in reports or other sources. Harvest reports published by Washington Department of Natural Resources could be used for this, since they are categorized by owner, product class, and species composition of sold product. However, the species compositions indicated in these reports are for product mixes only, and bear no correlation to stands from which the products may have originated. This would make the verification of simulated harvests matching actual harvests an arduous task at best.

Based on the above apparently unresolvable challenges (at least as regards to developing near-term solutions to them), actual harvest records obtained from either the Washington Dept. of Revenue and / or Washington Dept. of Natural Resources would be used instead of simulating them. This would avoid potential pitfalls and biases that might be introduced by incorrectly specifying a predominant management strategy for each ownership class in the process of trying to mimic actual harvests with a blanket prescription for each ownership class.

Washington Department of Natural resources personnel were contacted to obtain records on harvests over the past decade. We sought information on ownership class, harvest activity type (even-, or uneven-aged), acreage affected, and information on volume and species involved. We obtained a complete set of harvest reports for the past decade, which showed volumes removed by ownership, product class and species, but these reports lacked specific information on harvest type, and acreage involved (Larsen 1991 –1997, Larsen and Nguyen 1998, 1999, Anonymous 2000). Seeking more specific information to maximize accuracy, we were led to a forest practice permit application database maintained by the WA DNR MAPS unit. There we obtained a database containing specific information on ownership and acreage involved, but information on volume was deemed dubious because it was quite obvious that in too many cases volume units were clearly different from those which were requested on the permit application. Further, volume information was either not requested prior to 1995 or was not available for this study for some reason, as that information was very spotty. Further, no information at all was actually available on harvest activity type. This made the construction of specific treatments in the growth simulator to exactly coincide with actual harvests a nearly impossible task. Therefore, the published annual harvest reports available from the DNR were the best information available to estimate harvest removals from the carbon pool. To make use of these records, each stand was classified after simulation of forest growth according to its ownership and "product class" (essentially "age," either young growth, i.e., less than 100 years, or old growth greater than 100 years). Fortunately, the ownership classes used by the WA DNR coincide with the ownership classes used in the FIA PRIME database.

King County Forest Land Allocation by Ownership Class

The chief reason for considering ownership class in this study became one of desiring to match Washington timber harvest records of volume, which is given separately for each ownership and age (or product) class in the county, with the distribution of acreage among ownership classes represented by the field data. By matching the ownership classes used in this study as closely as possible with the classes used in the harvest reports would ensure that removals from the classes would impact the distribution of age classes remaining in each ownership class appropriately. The ownership classes chosen, as stated previously, were Forest Service, State, Forest Industry, Misc. Private, and County / Municipal / misc. federal.

Acreage in each forestland class in King County was taken directly from Table 7 of Bolsinger, et al. (1997). The distribution of forestland appears immediately below (Table 1).

Table 1. Area of forestland by land class in King County as reported in Bolsinger et al. (1997).

Forest Land Class	Area (acres)
Timberland	679,000
Reserved Timberland	60,000
Other Forest	37,000
Reserved Other Forest	45,000
Total	821,000

The distribution of timberland among ownership classes for King county is given in Table 10 of Bolsinger, et al. (1997) and appears immediately below (Table 2).

Table 2. Area of timberland by ownership class in King County as reported in Bolsinger et al. (1997).

Ownership Class	Area (acres)
Forest Industry	272,000
Misc. Private	138,000
State	61,000
Forest Service	114,000
County / Municipal / misc. federal	94,000
Total	679,000

The distribution of the other forestland classes among ownership classes is not given in Bolsinger, et al. (1997) for specific counties, but is given for Western Washington as a whole in their Table 9W. It is rewritten below, showing percentages by ownership class (Table 3).

Table 3. Area (% by acreage) of reserved forestland and other forestland among ownership classes in Western Washington inferred from Table 9W in Bolsinger et al. (1997).

Ownership Class	Reserved timberland	Reserved Other Forest	Unreserved Other Forest
Forest Industry	0.0%	0.0%	20.7%
Misc. Private	0.0%	0.0%	18.4%
State (DNR)†	24.3%	27.9%	6.6%
Forest Service	38.3%	29.2%	44.1%
County / mun. / misc. fed.†	37.4%	42.9%	10.2%
Total	100%	100%	100%

† Acreage in Bolsinger, et al. (1997) is given for "Other Public" which combines State with county / municipal / misc. federal. Therefore, the percentage in this class are imputed from the acreage in this class appearing in Table 1 of this study in proportion to the total of the two classes State plus county / mun. / misc. fed.

Therefore, the distribution of this other forestland acreage among ownership classes for King County was imputed from the distribution among owners in Western Washington as a whole. This was accomplished applying the proportional acreage figures from Table 3 to the actual acres from Table 1, and totaling the result with all acreage appearing in ownership classes of Table 2. The final distribution of forestland acreage in King county appears immediately below in Table 4.

Table 4. Area of all forestland by ownership class in King County as imputed from Tables 7, 9W and 10 from Bolsinger et al. (1997).

Ownership Class	Area (acres)
Forest Industry	279,659
Misc. Private	144,808
State (DNR)	90,553
Forest Service	166,437
County / Municipal / misc. federal	139,543
Total	821,000

As a check on this acreage distribution, the King county GIS database was consulted and the distribution of all land zoned as forestland appears immediately below in Table 5.

Table 5. Area of all land in King county zoned as forestland by ownership class as imputed from querying the King county database for all known taxpayer names contained therein.

Ownership Class	Area (acres)
Forest Industry	256,310
Misc. Private	35,205
State (DNR)	83,733
Forest Service	315,006
County / Municipal / misc. federal	119,178
Total	809,431

The total acreage figures are remarkably similar between Tables 4 and 5, namely 821,000 *versus* 809,431 varying only by 1.4%. The distribution among ownership classes, is quite similar also, except the Forest Service class has apparently swapped a large amount of acreage with the Misc. Private class. (Undoubtedly, other "trading" between classes has gone on, but the biggest visible differences are clearly between the two named classes.) Further investigation revealed that the differences between Tables 4 and 5 were due mainly to varying definitions of "non-industrial private" forestland and also, but chiefly due to parcels of land contained within the boundaries of the Mount Baker –Snoaqualmie National Forest having "dual ownership" status. That is to say, there are many acres within the boundaries of the MBS NF, which actually are owned by either Forest Industry or owned by miscellaneous private companies or individuals. Thus, the ownership acreage determined during the primary sampling phase of the PRIME inventory in 1989/90 taken from Bolsinger et al. (1997) was deemed the best estimate of the two as far as distribution of area among ownership classes is concerned. The acreage distribution appearing in Table 4 thus was used for updating the inventories within each ownership class.

It must be noted that reserved timberland is productive forestland and is imputed to have a composition of stand types similar to the timberland actually sampled in both the PRIME and MBS inventories. Reserved and unreserved other forest is also imputed to have a composition of stand types similar to the timberland actually sampled in both the PRIME and MBS inventories. It is possible that stocking on average will be lower than the sampled timberland class, given the definitions for these forestland classes in Bolsinger, et al. (1997). However, the acreage in these classes is less than 10% of the total forestland in King County. Further, stocking is probably not less than 50% of timberland on a countywide average basis, thus any potential bias in carbon figures for the county will have a strict upper bound of five percent.

Updating Inventory Data to Present

Various methods are available for updating inventory information. Of course, in a fully regulated forest, all growth equals drain, so the inventory in any given year is exactly equal to any other year (except during transition periods). Thus, the age distribution of the forest can be found at any time by "harvesting" the oldest age class, setting its age back to zero, and adding the elapsed time since the last inventory to each remaining age class. This approach may be applied successfully to very extensive forested areas, even those not under full regulation, with minimal error (see, for example, Lippke, et al. 2000).

Alternatively, a forest growth simulation model can be used to update the tree information separately for each plot. In this study, the Forest Vegetation Simulator (FVS) was used to update both the PRIME and MBS inventory data sets. FVS is an individual tree, distance independent growth and yield model that can portray a wide variety of forest types and stand structures ranging from even-aged to all-aged, single species to mixed in single to multi-storied canopies. FVS can simulate forest growth on a five-year cycle, which means that stand, stock and other tables of stand information can be generated every five years. FVS was originally called Prognosis (Stage 1973) and was developed for use in the Inland Empire area of Idaho and Montana. Many new variants of FVS have been developed and result when the existing equation forms in FVS for tree growth and mortality modeling in a particular geographic area are imbedded into the FVS framework. The West Cascade variant is one example of a variant of FVS.

Data for development of the the West Cascade variant came from the following National Forests: Mt. Baker-Snoqualmie, Gifford Pinchot, Mt. Hood, Willamette, Umpqua, and the Cascade Range portion of the Rogue River. This variant includes parts of several physiographic provinces as defined in Franklin and Dyrness (1973). From the north these include the Northern Cascades (Wash.), the Southern Washington Cascades, the Western Cascades (Ore.), and the High Cascades (Ore.). It applies to 37 specific tree species.

The Pacific Northwest (PN) variant might have been used for the inventory update, but the data used for the development of the PN variant came from the Olympic NF, the Siuslaw NF, the Quinalt Reservation, and the Inventory of BLM lands on the Oregon coast. The Olympic Peninsula and other coastal regions were considered to be less similar to the Puget Trough than the regions used as data sources for the WC variant. Therefore, the WC variant was used throughout the study.

The Landscape Management System (LMS), developed in the Silviculture Lab at the University of Washington, College of Forest Resources was used to facilitate data manipulation and inventory update simulation (McCarter et al. 1998). LMS requires two tables of information for its operation. One of the tables is the so-called Stand DataBase (SDB) file. The SDB file contains fields representing Stand ID, Plots, Location, Site Index, Eco-class, Age, Slope, Aspect, Elevation, Latitude, and Acreage. Data were extracted from each of the PRIME and MBS databases to conform to this format. Site index for the PRIME plots was taken to be the average of the Site Indexes found on the five sub-plots to produce a more stable estimate for use in simulating growth on each of the individual sub-plots. Averaging Site Index over a modestly sized "stand" (approx. 5ac) is not at all unusual. As stated previously, Eco-class was the only site quality indicator known for the MBS inventory plots, so this qualitative variable could not be averaged over the five sub-plots in that data set. Also, as mentioned previously, eco-class to site index conversions are handled internally to the WC variant of FVS, so no information is lost by not having site index.

The second table of information needed by LMS is the so-called stand inventory (INV) file which contains inventory tree records for all plots. Data was extracted appropriately from the PRIME and MBS databases to conform to this format including the following fields: Year, Stand ID, Tree number, Species code, DBH, Height, Crown Ratio, Trees Per Acre, Board-Foot Volume, Cubic-Foot Volume, Merchantable Cubic-Foot Volume (4" top), and Maximum Crown Width. Crown Ratio, Board-Foot Volume, Cubic-Foot Volume, Merchantable Cubic-Foot Volume and Maximum Crown Width were entered as zeroes to be calculated during the inventory rebuild process. In the inventory rebuild process, LMS directs FVS to calculate missing heights, crown ratios, volumes, and crown widths using equations embedded in the growth model.

In order to apply the harvest volume information found in the harvest reports to update the inventory data, it was necessary to make several assumptions. First, it was assumed that all harvested volumes came from clear fellings. From the perspective of carbon stored in trees on the stump in the forest, this is a reasonable assumption. If a certain volume in trees is removed, it is no longer in the forest adding to the carbon pool, and it is essentially irrelevant if the trees themselves were removed in a thinning or in a clear-cut, they are still removed from the pool. The net effect on carbon is therefore correct in a given year of harvest, but any attempt at estimating actual acreage in thinned or clear cut stands in that harvest year will be subject to error.

Second, it was assumed that each clear cut stand immediately would be replanted with the most prevalent species in the original stand mixture (up to three species) to achieve a density by age 10 of 400 trees per acre, a common industry target (Briggs and Trobaugh 2001). Therefore it was explicitly assumed that species conversions were not being implemented. Possibly incorrect species mixtures in the first 10 to 15 years of a simulated rotation is believed to have minimal impact on the total estimate of the carbon pool represented by the trees.

Third, since FVS simulates on a five-year cycle, of all actual harvests accumulated for the first half of the past decade, i.e., from 1991 –1995, half were assumed to occur in 1991, the other half to occur in 1995. Similarly, all harvests occurring in the latter half of the past decade, i.e., from 1996 –2000 were accumulated and half were assumed to occur in 1996 and the other half in 2000. This methodology maintains consistency with the way stands are used in this study, i.e., as representative of an owner / age class stratum, not as an individual stand. Therefore, this assumption is not expected to introduce an additional error in our estimates.

Fourth, it was assumed that the PRIME and MBS inventory information provides accurate (even if imprecise) average volume per acre statistics for the two recognized product classes (old/young growth) in the harvest reports. These county wide landscape averages over all site classes, species mixtures, actual age ranges and stocking variations within each product class are empirical product class yields in the truest sense and indicate that an old growth (stands aged > 100 years) acre in King County yields 66,994bd. ft. on average and a young growth (stands aged <100 years) acre in King County yields 17,938bd. ft. on average. When inverted, these numbers represent "acres per board foot" ratios and can then be used to translate board foot volumes reported in the annual harvest reports into "acreage equivalents" that represent the acreage that would have to be harvested on average over the county to achieve that volume.

Fifth, it was assumed that harvesting a typical acre of old or young growth in the half decade time periods considered in this study would yield a species distribution similar to what is found in the harvest reports. This assumption is tenable by virtue of the fact that the PRIME and MBS inventories are, in fact, representative of what is actually on the ground.

In order finally to produce estimates of the carbon pool represented by the standing trees, five "management" scenarios were run using LMS. The first management scenario represents the case where every owner did nothing. So this "no action" scenario estimates change in every stand assuming no harvest activity, just normal stand dynamic processes of growth, competition and mortality up to and including the year 2005. The second scenario represents the case where every owner clear-cut and replanted their stands in 1990, then let the stands grow until 2005. The third, represents the scenario where every landowner let their stands grow until 1995, then clear-cut them, replanted them, and grew them with no further action until 2005. The fourth scenario has owners letting the stands grow until 2000, at which time a clear-fell and plant is performed, growing the planted stands until 2005.

Though these scenarios will not be used in reality on the ground, they were utilized as a representation of reality in terms of producing realistic species mixtures of young, regenerated forests, because of the way we are weighting our acreage. It must be remembered that their sole purpose is to provide representative acres of new stands in these appropriate species mixtures and stages of stand development (i.e., zero years after harvest, five years after harvest, and ten years after harvest) in each half-decade. This allows the calculation of the carbon pool in each half decade by appropriately weighting each scenario by acreage remaining in the no action (unharvested) state and acreage in a harvested state (zero, five, or ten years after regeneration) in any given half decade and over time.

Estimating Sequestered Carbon from Current Inventory Information

The methodology used to estimate carbon from tree lists representing standing inventory was developed for a project which sought to develop a carbon accounting system that could be used to support Life Cycle Inventories by the Consortium for Research on Renewable Resources (Manrquez 2001). That study developed a prototype carbon sequestration analysis model for use with tree list inventory data representing current forest conditions and for use with growth model simulations (or updates) of inventory conditions to forecast future conditions. This carbon allocation system was linked with LMS to facilitate its use.

In its operation, the carbon estimation begins with converting volume content of trees from LMS inventory tables form English into metric equivalents. Then regression equations are used to predict (estimate) biomass in kilograms of the different tree components: live branches, stem and bark, and coarse roots.

Gholz (1979) developed the biomass equations used in this study. The equations to determine biomass in kilograms follow one of three forms, depending upon species of interest and biomass component of interest. The three possible equation forms are:

1. $B = e^{b0} * dbh^{b1}$
2. $B = b_0 + b_1 * dbh^2 * ht/100 - b_2 * (dbh^2 * ht/100)^2$
3. $B = b_0 + b_1 * (dbh^2 * ht/100)$

where, B = Biomass (kg),
dbh = Diameter Breast Height (cm),
ht = total height (m), and
b_0, b_1, b_2 are regression coefficients that are species and biomass component specific and appear in the appendix.

These equations have found applicability in several previous studies (Grier and Logan 1977, Harmon et al. 1990, Cropper and Ewel 1984, Canary et al. 1996). A general study into the distribution of standing crop biomass revealed that about 75% of the total above and below ground biomass exists in the wood and bark of stems (Cooper 1983) and around 15 –20% is contained in medium and coarse roots (Santantonio et al. 1977).

Tree carbon is then estimated by multiplying the biomass output from the equations above by a proportional factor that depends on the species taken from Birdsey (1992, Table 1) (Appendix 2). The carbon output is then summarized into three groups, stem (bark and wood), crown (foliage + branches – litter fall) and coarse roots. When coefficients from Gholz et al. (1979) were not available for a particular species encountered in the PRIME or MBS inventory data, suitable substitute species equations were used.

Finally, the county carbon pool is derived by summing all live tree components and expanding them appropriately according to the number of acres that each stand represents over the county landscape, then accumulating them into ownership / product classes so that harvest removals can be applied to appropriate acreage.

RESULTS AND DISCUSSION

Since the earliest inventory year common to both the (updated) PRIME inventory data and the MBS inventory data is 1995, static estimates of the live tree carbon pool will be reported beginning with 1995, are updated and given for 2000, and are forecasted under two different harvesting assumptions to 2005. The first forecasting scenario uses the assumption that harvest rate will continue for the next five years as it had in the past five. The second forecasting scenario uses the assumption that harvesting will occur similar to the average five-year rate calculated from the past ten years. The past, current and probably near-term future live tree carbon pool resulting from this study appear below (Table 6).

Table 6. The estimated carbon pool (metric tons) in live trees (stems, bark, live branches, coarse roots, and foliage less litterfall) on forestland in King County, projected over time.

Ownership Class / Product Class		Actual, Updated, or Forecasted Inventory year			
		1995	2000	2005[a]	2005[b]
		(metric tons)	*(metric tons)*	*(metric tons)*	*(metric tons)*
Forest Industry	/ old growth	449,111	470,545	491,572	491,572
	/ young growth	13,224,685	12,939,566	12,374,537	12,071,555
Misc. Private	/ old growth				
	/ young growth	9,457,434	9,675,425	9,721,302	9,721,804
State	/ old growth	1,448,980	1,492,952	1,534,815	1,534,478
	/ young growth	6,845,915	6,823,484	6,730,204	6,780,460
Other public	/ old growth				
	/ young growth	8,109,510	9,139,160	10,158,927	10,103,859
Forest Service	/ old growth[c]	7,412,618	7,967,593	8,139,367	8,139,367
	/ young growth	6,383,890	6,421,865	6,907,830	6,907,830
All owners	/ old growth	9,310,710	9,931,091	10,165,754	10,165,754
	/ young growth	44,021,434	45,009,499	45,892,799	45,585,508
All owners / All Product Classes		53,332,144	54,940,590	56,058,554	55,751,262

[a] Forecast based on rate of harvest similar to past five years, all harvests applied to young growth class.

[b] Forecast based on rate of harvest similar to past ten years scaled to a five year period, all harvests applied to young growth class.

[c] Changes in Forest Service old growth carbon values may include increases in acreage due to older young growth stands crossing the 100-yr threshold as well as growth on residual growing stock.

Average countywide tons of carbon per acre represented in these figures ranges from 64.9 tons / acre in 1995 to about 68.1 tons / acre in 2005. These numbers compare well with some published figures in the literature. These figures are affected principally by age, density of stocking, site class, stand structure, and species composition.

One feature of note is that the total carbon pool sequestered by trees growing in King County forests is increasing over time, despite a significant amount of harvesting that is being conducted. Harvested acreage equivalents between 1990 and 1995 represented approximately 7% of the forestland in the county, which represents roughly a 70-year average operating rotation (assuming even-aged harvesting systems predominate). We have also observed the impact of a distinct change in policy occurring in the latter half of the last decade, i.e., from 1996 to 2000. We noted that harvest acreage equivalents were approximately just 5% of the forested landscape for the period 1996 to 2000, a 28% drop from the former half of the last decade.

Limitations and Recommendations for Further Research

The simulation results presented here provide a generalized analysis of carbon on forestland in King County. The results are a representation of reality (a model) and many factors may cause projected results to deviate from what actually occurs on the ground. For example, catastrophic stand re-initiation events were not factored into this study. Neither were the effects of a changing climate accounted for. Beyond these largely unpredictable events or difficult to assess effects, there are still some refinements to the methodology that can be made.

For example, more precise estimates of empirical yields for old growth and young growth might be developed if separate empirical yield estimates were calculated for each ownership class. The empirical yield estimates might be refined even further by letting them vary with time. Another refinement that might improve the precision of the estimates would be to develop guidelines or specific silvicultural regimes for treating specific stands in the inventory data sets, rather than treating the "average acre" with an "average harvest" within each ownership. If this were done, carefully constructed acreage constraints would have to be developed so that harvests in a particular year would match the annual harvest for the county as found in the annual state harvest report.

Somewhat beyond the scope of this study, additional work might be conducted to investigate the impact that alternative silvicultural regimes may have on carbon sequestration. For example, preliminary results by Wayburn and Richards (1999) indicate that variable retention harvest systems may produce gains in sequestered carbon over conventional clear-fell systems.

Finally, the estimates that appear here apply to the carbon pool in standing trees only. Harvest removals were considered only to deplete the carbon pool in the forest. What happens to the sequestered carbon after it leaves the forest also should be considered. That is to say, larger questions regarding long-term sequestration in wood product pools would include those that revolve around life cycle analysis (see, for example Bowyer, et al. 2002). For example, much sequestered carbon is potentially stored for quite a long time in a house built of framed wood 2x4 construction. Answers to questions like this will help reveal all the missing pools and fluxes affecting both *in situ* and *ex situ* sources of sequestered carbon.

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APPENDIX 1

The following coefficient sets are taken from Manriquez (2001). The first number in each set refers to equation number (equations from text repeated below), then the three following numbers represent the b_0, b_1, b_2 coefficients, respectively. Species codes are as follows: BM= bigleaf maple, CO= black cottonwood, CH= bitter cherry, GF= grand fir, RA= red alder, WH= western hemlock, DF= Douglas-fir, RC= red cedar, AF= subalpine fir, SF= silver fir, NF= noble fir, WP= white pine, SS= sitka spruce, MH= mountain hemlock, PY= pacific yew, WA= white alder, PB= western paper birch, DG= pacific dogwood, YC= western larch.

Equations used:

1. $B = e^{b0} * dbh^{b1}$
2. $B = b_0 + b_1 * dbh^2 * ht/100 - b_2 * (dbh^2 * ht/100)^2$
3. $B = b_0 + b_1 * (dbh^2 * ht/100)$

Foliage Biomass

Spp.	Eqn.#	Coefficient set
BM =	1,	-3.7650, 1.6170, 0.0000
CO =	1,	-3.7650, 1.6170, 0.0000
CH =	1,	-3.7650, 1.6170, 0.0000
GF =	1,	-2.8462, 1.7009, 0.0000
RA =	2,	0.5124, 0.1298, 0.0000
WH =	1,	-4.1300, 2.1280, 0.0000
DF =	1,	-2.8462, 1.7009, 0.0000
RC =	1,	-2.8462, 1.7009, 0.0000
AF =	1,	-2.8462, 1.7009, 0.0000
SF=	1,	-2.8462, 1.7009, 0.0000
NF=	1,	-2.8462, 1.7009, 0.0000
WP=	1,	-2.8462, 1.7009, 0.0000
SS=	1,	-2.8462, 1.7009, 0.0000
MH=	1,	-4.1300, 2.1280, 0.0000
PY=	1,	-4.1300, 2.1280, 0.0000
WA=	2,	0.5124, 0.1298, 0.0000
PB=	2,	0.5124, 0.1298, 0.0000
DG=	1,	-3.7650, 1.6170, 0.0000
YC=	1,	-2.8462, 1.7009, 0.0000

RC uses same coefficients as DF. Original: RC=-2.6170, 1.7824, 0.0000

APPENDIX 1 (CONT'D)

Litter fall Biomass

Spp.	Eqn.#	Coefficient set
BM =	1,	-2.1160, 1.0920, 0.0000
CO =	1,	-2.1160, 1.0920, 0.0000
CH =	1,	-2.1160, 1.0920, 0.0000
GF =	1,	-3.5290, 1.7503, 0.0000
RA =	1,	-2.1160, 1.0920, 0.0000
WH =	1,	-2.4090, 1.3120, 0.0000
DF =	1,	-3.5290, 1.7503, 0.0000
RC =	1,	-3.5290, 1.7503, 0.0000
SF =	1,	-3.5290, 1.7503, 0.0000
NF =	1,	-3.5290, 1.7503, 0.0000
AF =	1,	-3.5290, 1.7503, 0.0000
SS =	1,	-3.5290, 1.7503, 0.0000
WP =	1,	-3.5290, 1.7503, 0.0000
WA =	1,	-2.1160, 1.0920, 0.0000
PB =	1,	-2.1160, 1.0920, 0.0000
MH =	1,	-2.4090, 1.3120, 0.0000
PY =	1,	-2.4090, 1.3120, 0.0000
YC =	1,	-3.5290, 1.7503, 0.0000
DG =	1,	-2.1160, 1.0920, 0.0000

RC uses same coefficients as DF. Original: RC=-2.0927, 2.1863, 0.0000

Root Biomass

Spp.	Eqn.#	Coefficient set
BM =	1,	-3.4930, 2.7230, 0.0000
CO =	1,	-3.4930, 2.7230, 0.0000
CH =	1,	-3.9493, 2.7230, 0.0000
GF =	1,	-4.6961, 2.6929, 0.0000
RA =	3,	0.1000, 0.4800, 0.0005
RC =	1,	-4.6961, 2.6929, 0.0000
WH =	1,	-4.6961, 2.6929, 0.0000
DF =	1,	-4.6961, 2.6929, 0.0000
WA=	3,	0.1000, 0.4800, 0.0005
PB=	3,	0.1000, 0.4800, 0.0005
AF=	1,	-4.6961, 2.6929, 0.0000
NF=	1,	-4.6961, 2.6929, 0.0000
SF=	1,	-4.6961, 2.6929, 0.0000
SS=	1,	-4.6961, 2.6929, 0.0000
WP=	1,	-4.6961, 2.6929, 0.0000
PY=	1,	-4.6961, 2.6929, 0.0000
MH=	1,	-4.6961, 2.6929, 0.0000
YC=	1,	-4.6961, 2.6929, 0.0000
CW =	1,	-3.4930, 2.7230, 0.0000
DG =	1,	-3.9493, 2.7230, 0.0000

APPENDIX 1 (CONT'D)

Live Branch Biomass

Spp.	Eqn.#	Coefficient set
BM =	1,	-4.2360, 2.4300, 0.0000
CO =	1,	-4.2360, 2.4300, 0.0000
CH =	1,	-4.2360, 2.4300, 0.0000
GF =	1,	-3.6941, 2.1382, 0.0000
RC =	1,	-3.2661, 2.0877, 0.0000
WH =	1,	-5.1490, 2.7780, 0.0000
DF =	1,	-3.6941, 2.1382, 0.0000
RA =	1,	-4.2360, 2.4300, 0.0000
NF=	1,	-3.6941, 2.1382, 0.0000
SF=	1,	-3.6941, 2.1382, 0.0000
AF=	1,	-3.6941, 2.1382, 0.0000
WA=	1,	-4.2360, 2.4300, 0.0000
PB=	1,	-4.2360, 2.4300, 0.0000
SS=	1,	-3.6941, 2.1382, 0.0000
WP=	1,	-3.6941, 2.1382, 0.0000
MH=	1,	-5.1490, 2.7780, 0.0000
PY=	1,	-5.1490, 2.7780, 0.0000
YC=	1,	-3.2661, 2.0877, 0.0000
CW=	1,	-4.2360, 2.4300, 0.0000
DG=	1,	-4.2360, 2.4300, 0.0000

Stem Biomass

Spp.	Eqn.#	Coefficient set
BM =	1,	-3.4930, 2.7230, 0.0000
CO =	1,	-3.4930, 2.7230, 0.0000
CH =	1,	-3.4930, 2.7230, 0.0000
GF =	1,	-3.0396, 2.5951, 0.0000
RA =	3,	0.0200, 1.6000, 0.0005
RC =	1,	-4.1934, 2.1101, 0.0000
WH =	1,	-2.1720, 2.2570, 0.0000
DF =	1,	-3.0396, 2.5951, 0.0000
AF=	1,	-3.0396, 2.5951, 0.0000
NF=	1,	-3.0396, 2.5951, 0.0000
SF=	1,	-3.0396, 2.5951, 0.0000
WA=	3,	0.0200, 1.6000, 0.0005
PB=	3,	0.0200, 1.6000, 0.0005
WP=	1,	-3.0396, 2.5951, 0.0000
SS=	1,	-3.0396, 2.5951, 0.0000
MH=	1,	-2.1720, 2.2570, 0.0000
PY=	1,	-2.1720, 2.2570, 0.0000
YC=	1,	-4.1934, 2.1101, 0.0000
CW=	1,	-3.4930, 2.7230, 0.0000
DG=	1,	-3.4930, 2.7230, 0.0000

APPENDIX 1 (CONCLUSION)

Bark Biomass

Spp.	Eqn.#	Coefficient set
BM =	1,	-4.5740, 2.5740, 0.0000
CO =	1,	-4.5740, 2.5740, 0.0000
CH =	1,	-4.5740, 2.5740, 0.0000
GF =	1,	-4.3103, 2.4300, 0.0000
RC =	1,	-4.3103, 2.4300, 0.0000
WH =	1,	-4.3730, 2.2580, 0.0000
DF =	1,	-4.3103, 2.4300, 0.0000
RA =	1,	-4.5740, 2.5740, 0.0000
NF=	1,	-4.3103, 2.4300, 0.0000
SF=	1,	-4.3103, 2.4300, 0.0000
AF=	1,	-4.3103, 2.4300, 0.0000
WA=	1,	-4.5740, 2.5740, 0.0000
PB=	1,	-4.5740, 2.5740, 0.0000
SS=	1,	-4.3103, 2.4300, 0.0000
WP=	1,	-4.3103, 2.4300, 0.0000
MH=	1,	-4.3730, 2.2580, 0.0000
PY=	1,	-4.3730, 2.2580, 0.0000
YC=	1,	-4.3103, 2.4300, 0.0000
CW=	1,	-4.5740, 2.5740, 0.0000
DG=	1,	-4.5740, 2.5740, 0.0000

APPENDIX 2

Factors to convert tree biomass to carbon (kg)

Region	Forest Type	Softwood	Hardwood
Rocky Mountain and Pacific Coast	Douglas-fir	0.512	0.496
	Ponderosa Pine	0.512	0.496
	Fir-Spruce	0.512	0.496
	Hemlock-Sitka Spruce	0.512	0.496
	Lodgepole pine	0.512	0.496
	Larch	0.512	0.496
	Redwoods	0.512	0.496
	Hardwoods	0.512	0.496

Source: Birdsey, R.A. 1992. Carbon storage and accumulation on United States forest ecosystems. USDA Forest Service General Technical Report. WO-59.